Water Chemistry of Ten Lakes in Southern New Brunswick: 1983 Survey

Richard H. Peterson and D. J. Martin-Robichaud

Biological Station,
St. Andrews, N. B., E0G 2X0

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WATER CHEMISTRY OF TEN LAKES IN SOUTHERN NEW BRUNSWICK: 1983 SURVEY

by

Richard H. Peterson and D. J. Martin-Robichaud

Fisheries and Environmental Sciences
Department of Fisheries and Oceans
Fisheries Research Branch
Biological Station
St. Andrews, N. B. EOG 2X0

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ABSTRACT

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Ten lakes in southern New Brunswick, which had been previously surveyed in 1978, were re-surveyed in 1983 to determine whether any changes in water chemistry had occurred. Lower lake pH levels in May and June 1983 were due to greater rainfall and warmer air leading to more rapid snow-melt in 1983 than was the case in 1978. Mid- to late-summer pH levels were similar both years.

A temporal increase in alkalinity deficits, as calculated from the Henriksen model, was associated with increasing groundwater influence from spring and early summer to late summer and early fall.

A background level of 40 µeq/L of $SO_4^=$ was estimated for southern New Brunswick lakes, as opposed to 20 µeq/L estimated for Scandinavian lakes.

RÉSUMÉ

Peterson, Richard H., and D. J. Martin-Robichaud. 1984. Water chemistry of ten lakes in southern New Brunswick: 1983 survey. Can. Tech. Rep. Fish. Aquat. Sci. 1299: iii + 23 p.

Dix lacs du sud du Nouveau-Brunswick, qui avaient été étudiés en 1978, l'ont été de nouveau en 1983 afin de détecter tout changement des propriétés chimiques de l'eau. Des précipitations plus abondantes et des températures de l'air plus élevées ont causé une fonte des neiges plus rapide en 1983 qu'en 1978 avec, comme conséquence des pH plus bas en mai et juin 1983. Au milieu et à la fin de l'été, les niveaux de pH étaient identiques les deux années.

Une augmentation, en fonction du temps, des déficits d'alcalinité déterminés selon le modèle de Henriksen est liée à une plus grande influence de l'eau souterraine du printemps et du début de l'été à la fin de l'été et au début de l'automne.

On a estimé à 40 µeq/L de $SO_4^=$ le niveau de référence pour les lacs du sud du Nouveau-Brunswick, comparativement à 20 µeq/L pour les lacs de Scandinavie.

INTRODUCTION

The monitoring of lake water chemistry and fish biota of 10 New Brunswick lakes was initiated in 1978 to assess the influence of acid precipitation. The water chemistry was to be monitored monthly, spring to fall, every 5th year, and the fish were to be investigated every 10th year. This report presents the data obtained from the water chemistry measurements produced in 1983, with appropriate comparisons with the 1978 data (Peterson 1980).

The intervening 5 yr have seen several technological advances in freshwater chemistry. For example, the ion chromatographic method is now considered the best technique for sulfate analysis, particularly for colored waters (Pollock and Komadina 1983; Howell and Kerekes 1983). The Gran plot of alkalinity titrations has become standard when estimating alkalinities. Because of the controversy over sulfate measurement, values obtained by both ion chromatography and colorimetry are included in this report, as are the dissolved organic carbon concentrations of the lakes.

METHODS

Sampling methods were identical to those of 1978. Analytical methods were also identical, except as follows: 1) sulfate was determined by both colorimetry and ion chromatography; 2) alkalinities were determined by Gran plots of titrations to an end point of 3.5, rather than the fixed end point titration to pH 4.5. pH and conductivity measurements were made on samples returned to the laboratory and aerated to air equilibrium at room temperature.

COMMENTS ON CHANGES IN STATUS OF LAKE DRAINAGES

Any changes in the lake drainage basins due to human activity are listed below. If a lake is not mentioned, it may be inferred that no apparent modification has occurred.

Mud Lake

One farm on the western side of the road running along the western side of the lake has been abandoned.

Bolton Lake

Some of the Bolton Lake drainage basin was being actively logged, as was the case in 1978. These activities did not approach the lake margin.

Wheaton Lake

No change with respect to human activity. Successional progression of plant communities proceeding from the 1968 burn of the drainage basin is continuing.

Stein Lake

One cottage near the lake outlet has been removed, and the road to the lake has deteriorated over the past 5 yr.

Kerr Lake

One new cottage was noted since 1978.

Mill Lake

The road skirting the western side has seen continued development. A few months after termination of 1983 sampling, the lake was contaminated by a spill of hydrofluorosilicic acid as a result of truck overturn. The spill site was subsequently heavily limed to within 30 m of the shoreline.

Chisholm Lake

The lake is still leased by a private fishing club; however, a logging contractor cut to the margin for about 50 m of shoreline.

RESULTS

In general the period spanning May to October 1983 was warmer and wetter than the same months of 1978 (Fig. 1, 2). The thermal units accumulated by the end of April in 1983 were more than double those accumulated to that date in 1978 (Fig. 1). Consequently, most lakes were warmer during the May sampling. The air in September and October was also warmer in 1983. The greater amount of precipitation in April-May 1983 than in 1978 (Fig. 2) had a profound influence on the lake water chemistry in May and June.

The cumulative wind and rainfall vectors for the 6 mo sampling period demonstrated a predominantly south-south westerly influence (Fig. 3, 4), while the dominant vectors were due south in 1978.

The mean chloride concentrations for all lakes were lower in 1983 than in 1978 (Fig. 5) throughout the sampling period. The mean difference between the two sampling periods was 18 µeq/L. Sodium concentrations for 1983 were also lower than in 1978 (Fig. 6), although the mean difference was only 9 µeq/L.

As in 1978, the Na:Cl ratios were highest through mid-summer, and lower in spring and fall (Fig. 7). Chloride concentrations again did not show the seasonal pattern exhibited by other ions (e.g. Na^+), which tend to become more concentrated as the summer progresses.

The lakes were generally warmer in May 1983 than in May 1978 (Fig. 8) - no doubt related to the warmer air temperatures, as discussed above. Bolton, the largest lake in the survey, tended to warm up more slowly than the others.

Conductivities measured in 1983 bore no consistent relation to those measured at similar times of year in 1978 (Fig. 9). Six of the 10 lakes had lower mean conductivities in 1983, one had higher conductivity in 1983 (Mill Lake), while the mean conductivities for the other lakes were identical.

The pH of Mud Lake was low in May and June (6.2-6.4, Fig. 10), compared to typical mid-summer values. By July the pH had risen to near that for the lake in 1978, although averaging about 0.2 pH units lower during July-October. The pH of Creasey Lake was less than 6.0 for May-June, then remained consistently 6.5-6.7 for the rest of the summer, 0.2-0.3 units lower than for the same period in 1978. The pH measurements for Bolton Lake in 1983 were similar to those made in 1978 except for the low June value. The pH's measured for Kerr and

Chisholm Lakes in 1983 were virtually the same as those measured in 1978 at similar dates. The pH's measured from Mill Lake water samples were 6.2 in May-June (Fig. 10), then rose to levels similar to 1978 for July-October. The pH's measured from Mosquito Lake were similar to those measured in 1978. Summer and fall pH's for Robin Hood Lake were consistently higher than 1978 values. Stein and Wheaton Lakes exhibited a somewhat typical pattern of low pH's in May-June, followed by a rise to 1978 levels in July-October.

The excess K^+ concentrations tended to be lower in 1983 (Fig. 11). The regression of mean 1983 K^+ values on mean 1978 values is $K^+_{83} = 0.80\ K^+_{78} - 0.18$ (r=0.93). Calcium also tended to be in lower concentrations in 1983 (Fig. 12). These regressions are greatly influenced by the relatively low 1983 concentrations of K^+ and Ca^{++} in Mud Lake. If Mud Lake were excluded from the regressions, the Ca^{++} regression in particular would lie near the line of equality. Even exluding Mud Lake, the K^+ concentrations were lower, on the average, in 1983 than in 1978. The lower concentrations of K^+ and Ca^{2+} are probably due to dilution by the greater 1983 rainfall.

The lakes in the survey are not highly colored, with mean dissolved organic carbon (DOC) ranging from 2.5-6 mg/L (Table 1). There was no significant correlation between DOC and difference in SO_4^{2-} concentrations determined by the two methods (Fig. 13). There was a consistent difference in values obtained by the two methods with ion chromatographic values consistently 5 μeq/L lower than colorimetric values (Fig. 14) the colorimetric values are probably biased a bit high (T. L. Pollock, personal communication). Since the colorimetric method was used in 1978, 1983 SO_4^{2-} values obtained by this method will be used for comparison between the 2 yr. The regression of 1983 SO_4^{2-} values on 1978 values (Fig. 15) indicates that lakes with higher SO_4^{2-} levels tended to have lower sulfates in 1983 (e.g. Kerr, Creasey, Stein). Lakes with low SO_4^{2-} levels tended to have higher sulfates in 1983 (e.g. Chisholm, Mosquito, Robin Hood). This would result if pptn. $SO_4^{=}$ concentrations were greater than that of low sulfate lakes but lower than those of high sulfate lakes - due to greater precipitation influence in 1983 (comment by T. L. Pollock). Sulfate measurements for Mud Lake were extremely low in 1983 and are excluded from the regression.

The humic content of the 10 lakes (as measured by color in Hazen units) is low (Table 2). Lakes, the color of whose waters are ≤ 10-15, are generally considered to be "clear water" lakes. It is apparent from Table 2 that all the lakes, except Robin Hood and Mill, may be regarded as "clear water" lakes (as opposed to humic or brown water lakes). Mill and Robin Hood Lakes are marginal with respect to this classification.

Levels of (DOC) are frequently highly correlated with color and are used as an indication of humic materials. The variation in DOC concentrations among these lakes, however, is not well correlated with color (Tables 1, 2), probably due to the low range of color values among the lakes. Mud Lake has the highest mean DOC level but is not highly colored (mean of 10 Hazen units). Among the other nine lakes, the correlation is better. Mill and Robin Hood Lakes are the more highly colored, and have relatively high DOC's (ca. 4.5), while Mosquito, Creasey, and Kerr Lakes all have low DOC's and low color. Seasonal variation in color does not correlate well with seasonal variation in DOC. Whereas color is usually most intense in May-June (see Bolton, Chisholm, Robin Hood, Stein, Table 2), the DOC's tended to be highest in July-September. In view of the low humic acid content of these lakes, it was decided to neglect any humic effects when deriving possible acidification estimates, an accepted procedure with "clear water" lakes (e.g. Wright and Henriksen 1983). It may be pointed out, nevertheless, that there is a good correlation between the anion deficit (as derived from ionic balancing procedures) and C_t (= the concentrations of organic anions as estimated from Oliver's (1982) equation (C_t = 10 x DOC) (Fig. 16). For lakes with a balance between anions and cations (Creasey, Mosquito), a "back-ground" C_t of 28 is predicted from the regression. If this is subtracted, then there is nearly a 1:1 relationship between cation excess and derived organic anion concentration. There is some doubt as to the nature of the organic ions. Much of the DOC in Mud Lake, for example, is not humic and is in highest concentration in lakes of highest pH (e.g. Mud, Mill, Wheaton), and probably of highest productivity.

Henriksen (1982) proposed a model to estimate bicarbonate alkalinities which should be present in the absence of any acidification. The model used the concentrations of excess Mg^{2+} and Ca^{2+} to estimate HCO_3^- concentrations prior to acidification which could be compared with measured CO_3^- levels. The equation proposed by Henriksen is: alk. = -14 + 0.93 (Ca^{2+} + Mg^{2+}). Differences between estimated and measured concentrations yield an alkalinity "deficit" - presumed to be lost through acidification. Since all lakes in this study have a mean pH > 5.4, Al^{3+} has been neglected when calculating alkalinity deficits (Wright and Henriksen 1983). These estimates of deficits are not corrected for possible changes in leaching rates of Ca^{2+} and Mg^{2+} as a result of increased precipitation acidity. Such a correction would probably result in a decrease in alkalinity deficit of about 20% (Wright and Henriksen 1983). Monthly alkalinity "deficits" for the 10 lakes (Table 3) indicate that the calculated "deficits" vary with the month. Most lakes have maximum deficits occurring in mid to late summer. Since the calculated "deficit" is a function of the excess Ca^{2+} and Mg^{2+} present, deficits and Ca^{2+} + Mg^{2+} levels were normalized with respect to individual lake means, so that the relationships between seasonal changes in deficits and excess Ca^{2+} + Mg^{2+} could be examined (Table 3, 4; Fig. 17). Alkalinity deficits were normalized on a monthly mean basis for nine lakes (excluding Bolton). Wheaton Lake would have an overpowering effect if individual monthly values for each lake were normalized. (This resulted in a conservative estimate of deficits.) Ca^{2+} + Mg^{2+} levels increased by about 50% over the course of the summer, while the alkalinity deficit increased by 75-80% (Fig. 17). In contrast, normalized sulfate levels show little or no increase over the summer (Table 5, Fig. 17).

Each lake is considered individually in Table 6. Here the temporal increases from May-June to August-September in Ca^{2+} + Mg^{2+}, alkalinity deficit, HCO_3^-, and SO_4^{2-} are estimated. If all the original Ca^{2+} + Mg^{2+} were associated with HCO_3^-, then these divalent cation sums for individual lakes in column 1 in Table 6 should be balanced by the sum of values in columns 2 and 3. This appears to be true for most of the lakes, with Bolton being the most

exceptional. The alkalinity deficit for Bolton may be overestimated. If sulfate salts of Ca^{2+} or Mg^{2+} were being leached into the lakes, one would expect SO_4^{2-} to increase through the summer as well. Only in Chisholm Lake does the increase in SO_4^{2-} approach the magnitude of the $Ca^{2+} + Mg^{2+}$ temporal increase.

A major fraction of the excess SO_4^{2-} is presumed to be of anthropogenic origin, and to be associated with acidification. It is reasonable to suppose, therefore, that lakes with higher SO_4^{2-} levels should exhibit greater alkalinity deficits. The regression of alkalinity deficit on excess SO_4^{2-} is A = 48.6-1.10 SO_4^{2-} excess (r = 0.84, Fig. 18). The SO_4^{2-} intercept at zero alkalinity deficit is 44 µeq/L. If the causal relationship between alkalinity deficit and excess SO_4^{2-} is genuine, then "background" SO_4^{2-} is about 40 µeq/L.

Henriksen (1982) has also produced a diagram to illustrate the relationships among alkalinity, excess sulfate, and precipitation pH for Norwegian lakes. A similar diagram, in histogram format, for the 10 New Brunswick lakes has been modified to incorporate 40 µeq/L for non-marine sulphate as background, rather than the 20 µeq/L that Henriksen used for Norwegian lakes (Fig. 19). The mean non-marine SO_4^{2-} above "background" for the 10 lakes 30.5 µeq/L, and the mean alkalinity "deficit" was 27.4 µeq/L.

DISCUSSION

Henriksen has developed the concept of estimating alkalinity losses from the relationships believed to exist among HCO_3^-, Ca^{2+}, and Mg^{2+} concentrations in "pristine" freshwater systems. Based on this concept, an alkalinity "deficit" may be calculated as the difference between actual and predicted HCO_3^- levels.

The calculated alkalinity "deficit" for the N.B. lakes varied temporally through May-October, 1983, with low deficits calculated in spring and early summer, and maximal deficits in August-September, approximately a mirror image relationship with the temporal variation in hydrogen ion concentrations in the lakes. The following hypothesis is advanced to offer an explanation of the temporal pattern in alkalinity deficits derived from the 1983 data: The major influence on lake water chemistry in May-June was that of precipitation and snowmelt. These sources are low in alkalinity. Since HCO_3^- is low in the lake water at this time, the pH remains low. With temporal progression through the summer the ground water influence (relatively high in Ca^{2+}, Mg^{2+} and HCO_3^-) increases its impact on lake water chemistry. The H^+ reacts with the increasing $[HCO_3^-]$ creating a greater "deficit" in the late summer months and thereby increasing the pH.

It is essential that these temporal changes in pH, alkalinity deficit, and excess $Ca^{++} + Mg^{++}$ concentrations be recognized when assessing the impacts of acid precipitation. In the spring (April-early June), the lake water chemistry may be greatly influenced by snowmelt and high precipitation. As a result, the pH is low as are Ca^{++} and Mg^{++} concentrations and alkalinity deficits. In July-October the influence of groundwater on lake water chemistry is more pronounced, resulting in higher pH levels, Ca^{++} and Mg^{++} concentrations and the concentrations and the generation of a greater alkalinity deficit.

The regression of SO_4^{2-} concentrations on deficits is such that a concentration of 40 µeq/L excess $SO_4^{=}$ is equated with zero alkalinity deficit. This is double that proposed by Henriksen as the "background" excess $SO_4^{=}$ level for Norwegian lakes. Thus, if one constructs nomograms of the Henriksen type for Norwegian lakes, a background of 20 µeq/L would over-estimate the acidification that may have occurred in these New Brunswick lakes. For example, with a background SO_4^{2-} level of 20 µeq/L, Mosquito Lake should be "acidic" with an excess of H^+. A background of 40 µeq/L excess SO_4^{2-} yields an interpretation more consistent with existing pH's and alkalinity levels.

In the previous report on water chemistry of these lakes (Peterson 1980), it was suggested that the temporal pattern of Na:Cl ratios observed in these lakes might be due to Cl^- uptake by aquatic plants. The ratios exhibited a similar temporal pattern in 1983; however we have an alternate suggestion which may be a more likely explanation of the pattern. It has been calculated that Na^+, on the average, is present in excess of Cl^- by 30 µeq/L, based strictly upon what would be expected from sea-salt introductions. If this extra Na^+ is from other, terrestrial sources (extraterrestrial Na^+?), then the observed temporal pattern of Na:Cl change could be explained on the basis of increased groundwater influence in mid to late summer. This would raise the $[Na^+]$ relative to $[Cl^-]$. During periods of high rainfall, such as spring and fall, the sea salt input becomes more important, and the ratio tends to approach that of sea water more closely.

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Table 1. Dissolved organic carbon (mg/L) in the various lakes.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	3.0	4.7	6.2	7.5	8.3	7.3	6.2
Bolton	-	4.6	4.1	4.8	3.8	3.7	4.2
Chisholm	4.1	4.3	4.9	5.1	3.9	4.8	4.5
Robin Hood	3.8	5.0	5.0	4.1	4.2	4.2	4.4
Mosquito	1.9	4.1	2.5	2.3	1.7	2.3	2.7
Creasey	1.8	3.1	3.5	3.0	0.5	3.2	2.5
Kerr	2.5	3.5	4.3	3.4	3.4	4.0	3.5
Stein	3.6	4.3	4.9	3.9	4.7	4.5	4.3
Wheaton	3.1	6.3	17.5[a]	3.4	3.4	3.5	4.0
Mill	4.2	5.3	4.0	5.3	4.4	5.1	4.7

[a]Possibly anomalous, not utilized in calculating the mean.

Table 2. Color (absorbance at 400 nm x 260) of water in the various lakes (Hazen units).

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	5	10	10	20	10	5	10.0
Bolton	-	20	10	10	<5	5	10.0
Chisholm	15	20	10	10	10	5	11.7
Robin Hood	30	30	20	10	10	5	17.5
Mosquito	<5	5	<5	<5	<5	<5	<5.0
Creasey	<5	<5	<5	<5	<5	<5	<5.0
Kerr	5	10	5	5	5	<5	5.0
Stein	15	10	10	5	5	5	8.3
Wheaton	5	5	<5	5	5	<5	<5.0
Mill	20	30	25	20	25	10	21.7

Table 3. Alkalinity deficits (μeq/L), as indicated by differences between measured alkalinities and theoretical alkalinities predicted by the equation: alk. = -14 + 0.93 (Ca^{2+} + Mg^{2+}). Deficits are calculated for each lake on a monthly basis. A negative value indicates that the measured alkalinity is less than theoretical. Values for Bolton Lake are excluded from means, as is the October value for Mill Lake.

Lake	May	June	July	Aug.	Sept.	Oct.	Mean
Mud	+6.8	+3.6	-34.0	+4.9	-59.0	-12.3	-15.0
Bolton	-	-	-29.9	-36.1	-44.2	-30.9	-35.3
Chisholm	-24.3	+8.6	-9.0	-10.4	-11.2	-22.5	-11.5
Robin Hood	-20.0	-25.9	-29.0	-44.4	-30.1	-35.1	-30.8
Mosquito	-7.6	-13.2	-12.9	-25.0	-15.8	-22.0	-16.1
Creasey	-23.7	-30.2	-46.4	-38.0	-23.8	-40.7	-33.8
Kerr	-23.5	-23.3	-29.3	-46.9	-35.3	-38.4	-32.8
Mill	-30.1	-30.3	-38.0	-31.6	-28.8	-100.9[a]	-31.8
Stein	-49.5	-40.5	-50.7	-47.0	-51.3	-39.3	-46.4
Wheaton	+5.0	+4.9	-3.5	-7.5	-7.7	+2.2	-1.5
Monthly Means (normalized means)	-18.5 (.72)	-16.1 (.63)	-27.0 (1.05)	-26.7 (1.04)	-28.3 (1.10)	-26.0 (1.01)	-25.7 (1.00)

[a]Anomalous value.

Table 4. Normalized monthly excess ($Ca^{2+} + Mg^{2+}$) concentrations in various lakes. Bolton Lake was omitted as May data were lacking.

Lake	May	June	July	Aug.	Sept.	Oct.
Mud	0.77	0.87	1.07	1.12	1.12	1.05
Chisholm	0.89	0.90	0.89	0.98	1.03	1.30
Robin Hood	0.86	0.92	1.05	1.04	0.93	1.20
Mosquito	0.93	0.81	1.12	1.01	1.04	1.09
Creasey	0.96	0.90	1.08	0.99	1.01	1.05
Kerr	0.91	0.91	0.93	1.08	1.07	1.10
Mill	0.90	0.90	1.00	1.09	1.06	1.04
Stein	0.75	0.84	0.95	1.08	1.20	1.18
Wheaton	0.94	0.89	1.00	1.04	1.06	1.12
Mean	0.88	0.89	1.00	1.04	1.06	1.12

Table 5. Normalized monthly excess $SO_4^{=}$ concentrations in the various lakes. Bolton Lake was omitted as May data were lacking.

Lake	May	June	July	Aug.	Sept.	Oct.
Mud	1.06	0.97	0.97	0.97	1.06	0.96
Chisholm	0.92	0.91	0.85	1.18	1.07	1.07
Robin Hood	1.03	1.05	0.95	0.82	1.20	0.94
Mosquito	1.01	1.00	–[a]	0.85	1.10	1.03
Creasey	0.96	0.97	0.94	1.00	1.09	1.04
Kerr	1.01	1.02	0.93	1.01	1.01	1.01
Mill	0.97	0.98	0.94	1.06	1.05	–[a]
Stein	1.02	1.03	–[a]	0.97	1.03	0.95
Wheaton	0.92	1.05	0.96	1.13	1.04	0.90
Mean	0.99	1.00	0.94	1.00	1.07	0.99

[a]Anomalous value omitted from normalization.

Table 6. Seasonal differences (May-June vs Aug.-Sept.), excess divalent cation totals, alkalinity deficits, HCO_3^- and $SO_4^{=}$ excess for the various lakes (μeq/L).

Lake	(1) $Ca^{2+} + Mg^{2+}$	(2) Alk. deficit	(3) HCO_3^-	(4) SO_4^{2-}	1-(2+3)
Mud	130-140	30-35	90-100	0	ca.0
Bolton	100-110	40	90-100	0	-(20-30)
Chisholm	15	0-5	0-5	10-15	0-5
Robin Hood	10-15	15	0	0-(-3)	ca.0
Mosquito	10	10	0	0	ca.0
Creasey	10	5	0.5	5	ca.0
Kerr	15-20	15-20	0	0	ca.0
Mill	25-30	0	25	5	ca.0
Stein	75	5	60	0-3	+10
Wheaton	15-20	10-15	2-3	0-5	ca.0

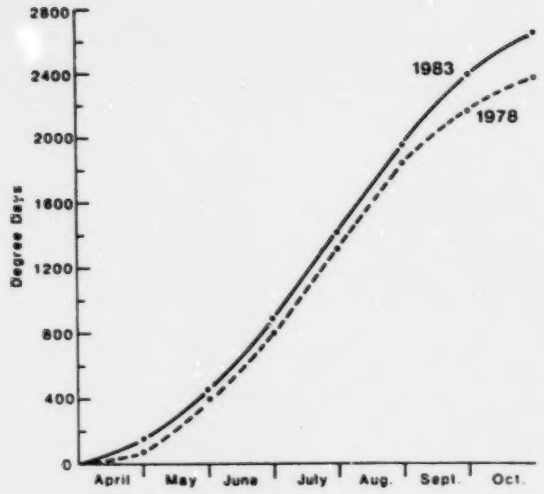


Fig. 1. Cumulative air degree-days are plotted for April-October, 1978 (dashed line) and 1983 (solid line).

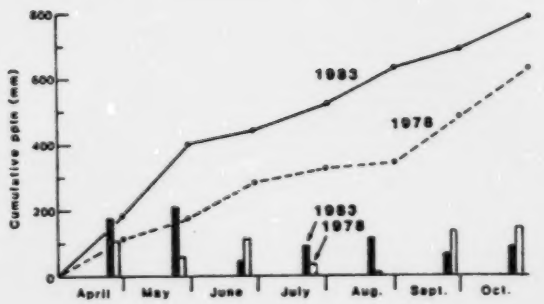


Fig. 2. Monthly and cumulative precipitation for 1978 (open bars, dashed line) and 1983 (solid bars, solid line), as derived from weather reports issued from the Saint John airport weather station.

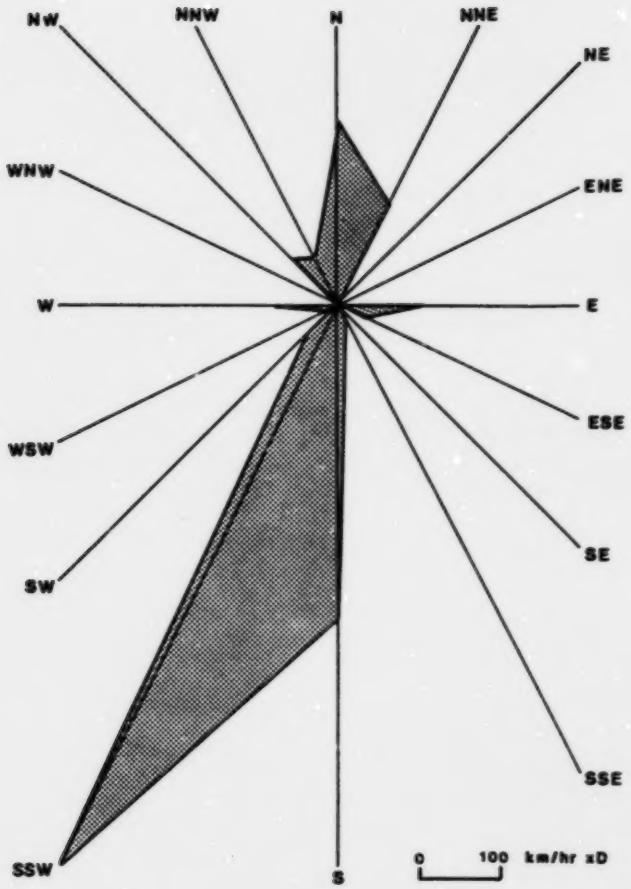


Fig. 3. Cumulative wind vectors for various compass sectors, as derived from weather reports issued from the Saint John airport weather station. The center of the vectors is Saint John.

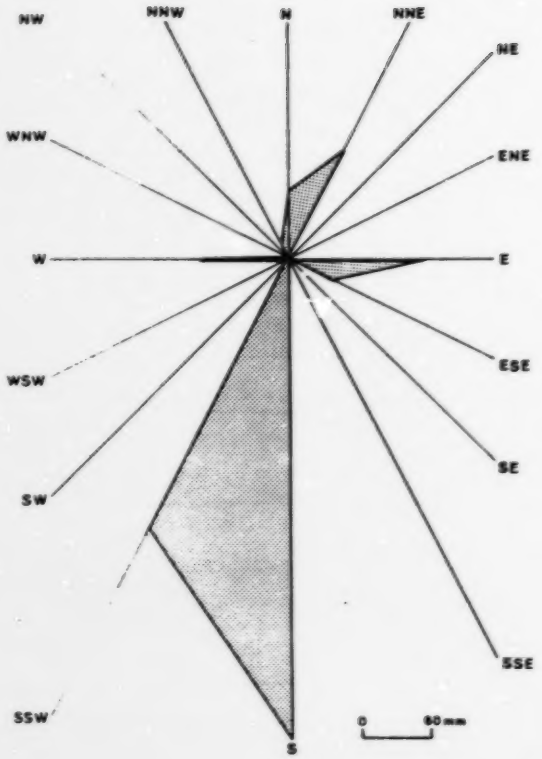


Fig. 4. Cumulative precipitation originating from various compass sectors as derived from weather reports issued from the Saint John weather station.

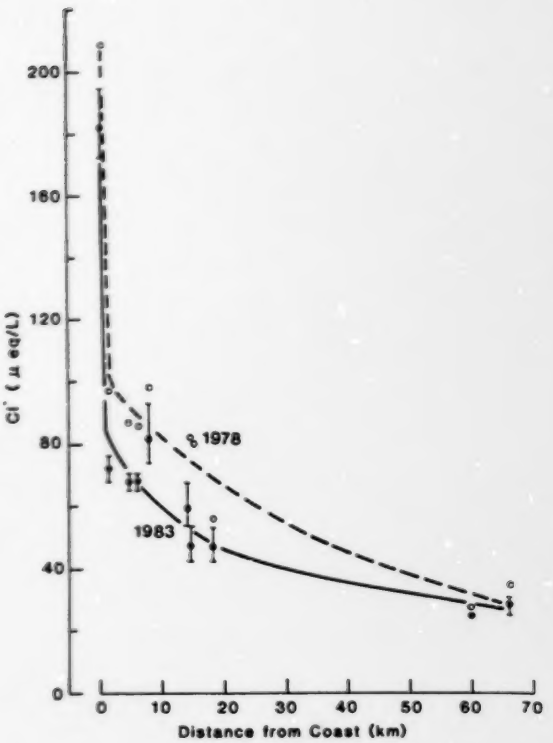


Fig. 5. Mean chloride concentrations in the 10 N.B. study lakes for May-October, 1978 (open circles, dashed line) and 1983 (closed circles, solid line), as related to distance from the coast. Lines are fitted by eye.

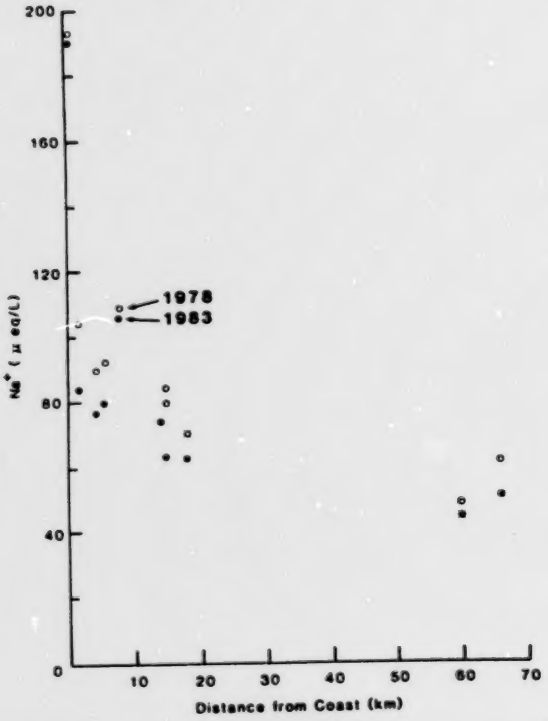


Fig. 6. Mean sodium concentrations in the 10 N.B. for 1978 (open circles) and 1983 (solid circles), as related to distance from the coast.

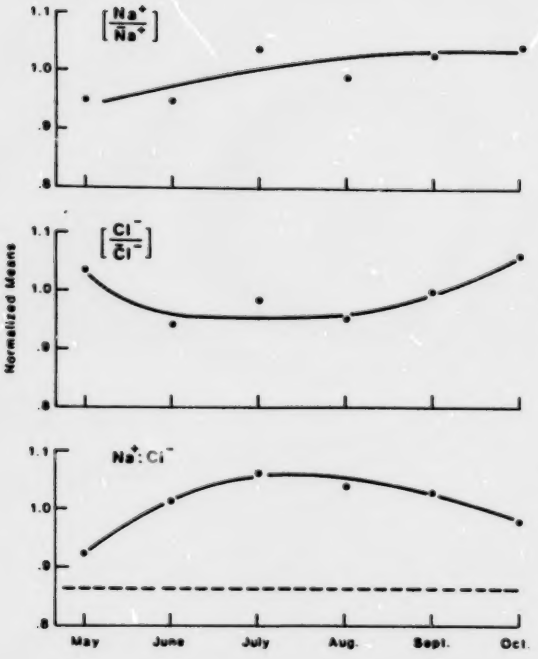


Fig. 7. Top panel: normalized mean Na^+ concentrations for 9 N.B. lakes (excluding Bolton) for May-October, 1983. Line fitted by eye.

Middle panel: Normalized mean Cl^- concentrations for 9 N.B. lakes for May-October, 1983.

Lower panel: Na^+:Cl^- ratios for normalized means from May to October. The dashed line indicates Na^+:Cl^- ratios for sea water.

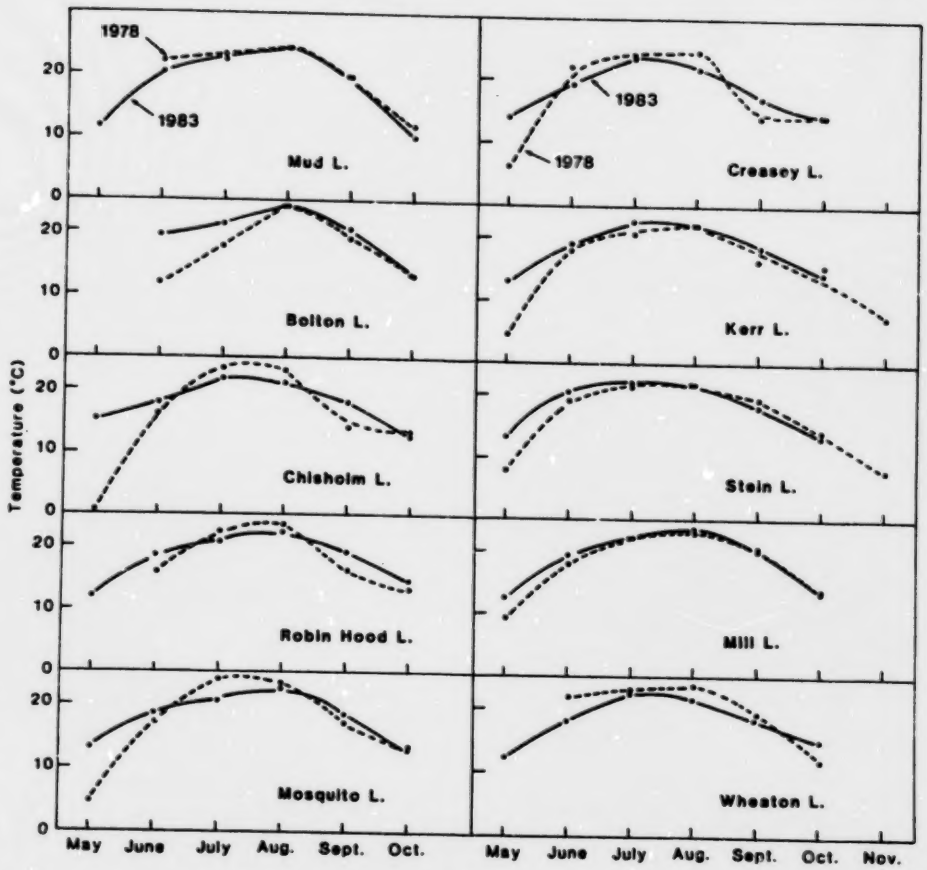


Fig. 8. Lake surface temperatures (°C) for the 10 study lakes from May to October, 1978 (dashed line) and 1983 (solid line).

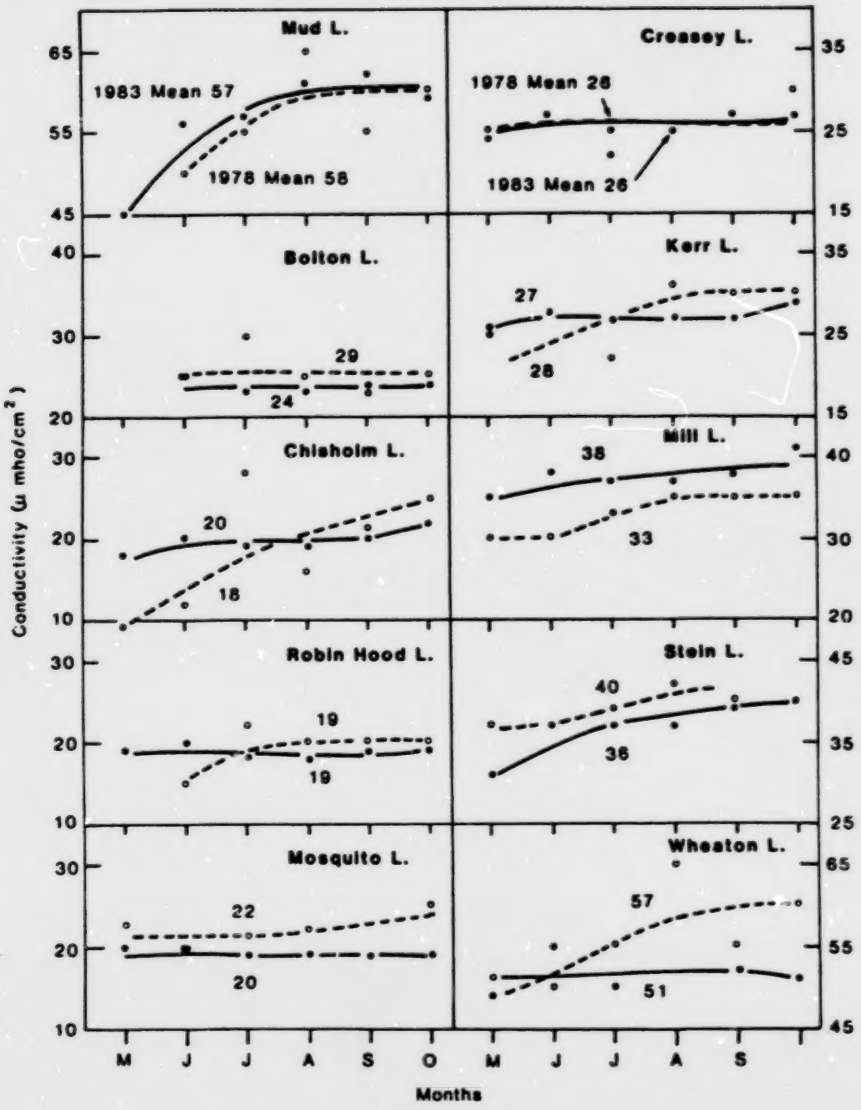


Fig. 9. Surface water conductivities for the 10 study lakes in 1978 (dashed line) and 1983 (solid line).

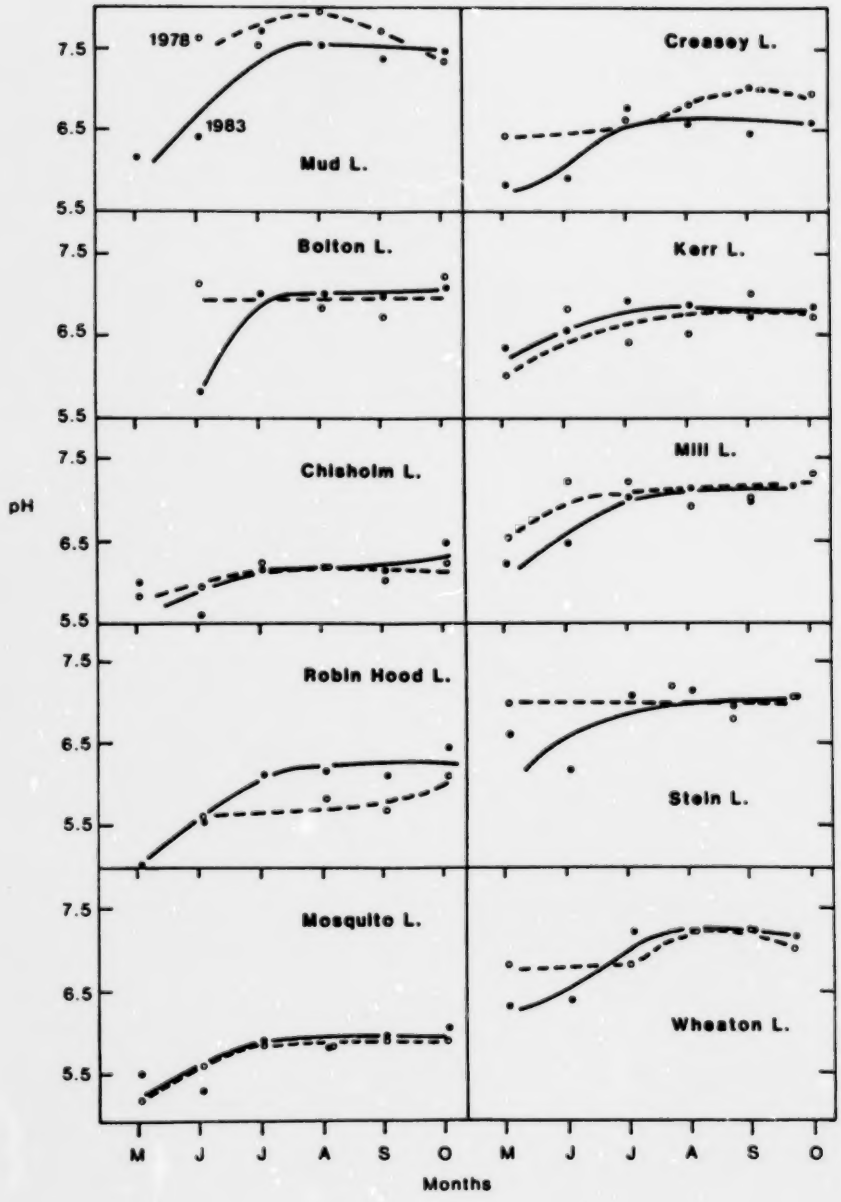


Fig. 10. Surface pH values for the 10 study lakes in 1978 (dashed line and 1983 (solid line). Lines fitted by eye.

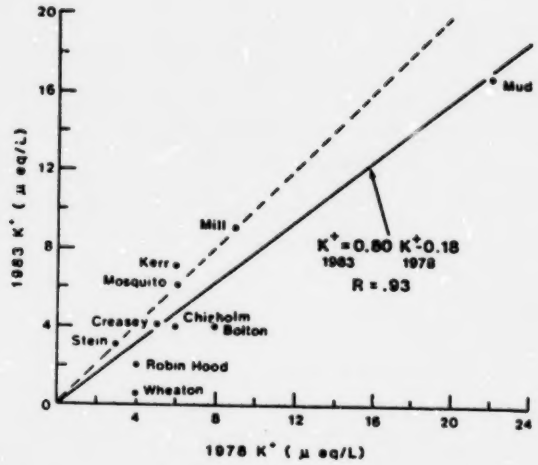


Fig. 11. Mean 1983 K^+ concentrations for the 10 study lakes are plotted vs the mean 1978 concentrations. The dashed line is the line of equality.

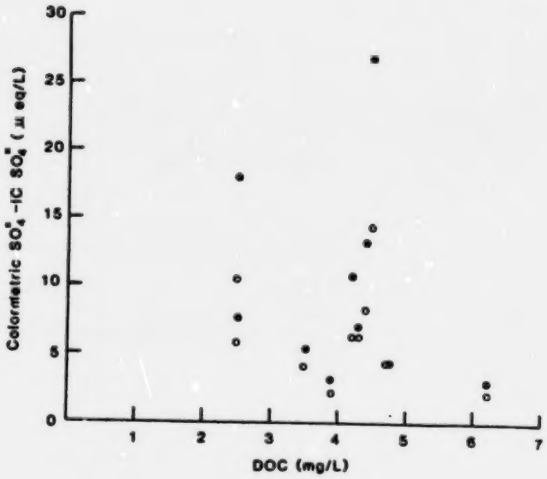


Fig. 13. Difference between mean 1983 SO_4^{2-} concentrations as determined by colorimetry and by ion chromatography for each of the 10 study lakes, plotted vs the dissolved organic carbon concentrations. Solid circles indicate absolute difference in μeq/L. Open circles indicate the % difference (same scale).

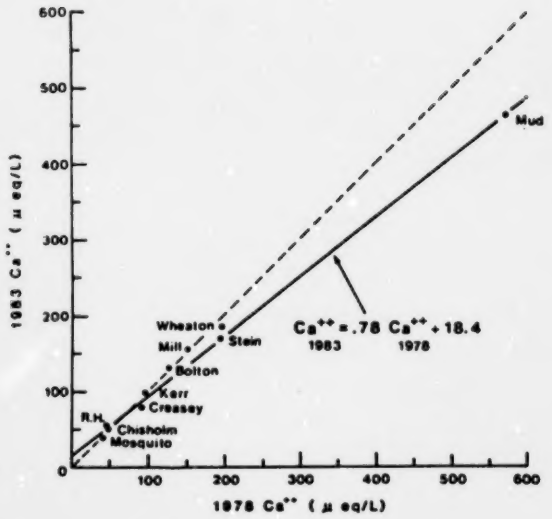


Fig. 12. Mean 1983 Ca^{2+} concentrations for the 10 study lakes are plotted vs the mean 1978 concentrations. The dashed line is the line of equality.

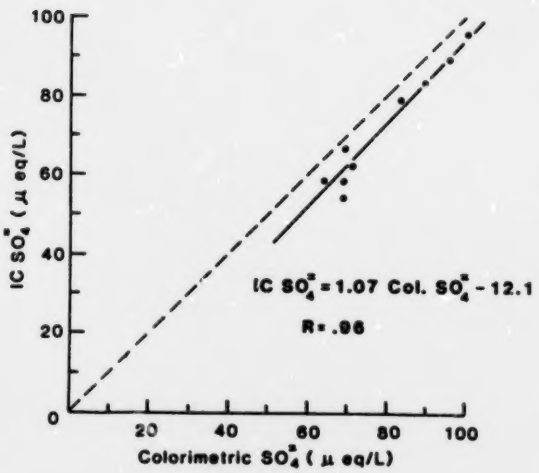


Fig. 14. Mean $SO_4^=$ concentrations determined by ion chromatography are plotted vs mean values determined by colorimetry for the study lakes. Dashed line is the line of equality.

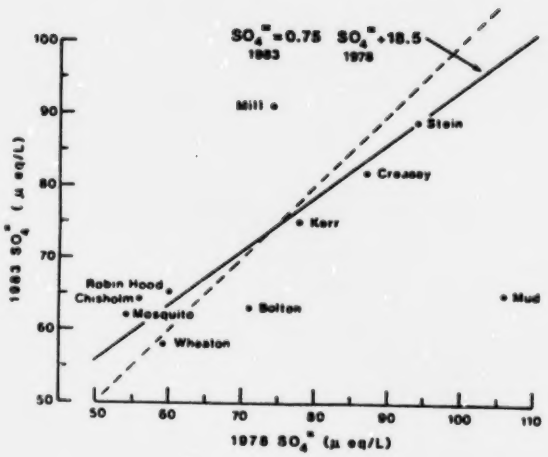


Fig. 15. Mean 1983 sulphate concentrations for the study lakes are plotted vs 1978 values. Mud L. was excluded from the regression calculation.

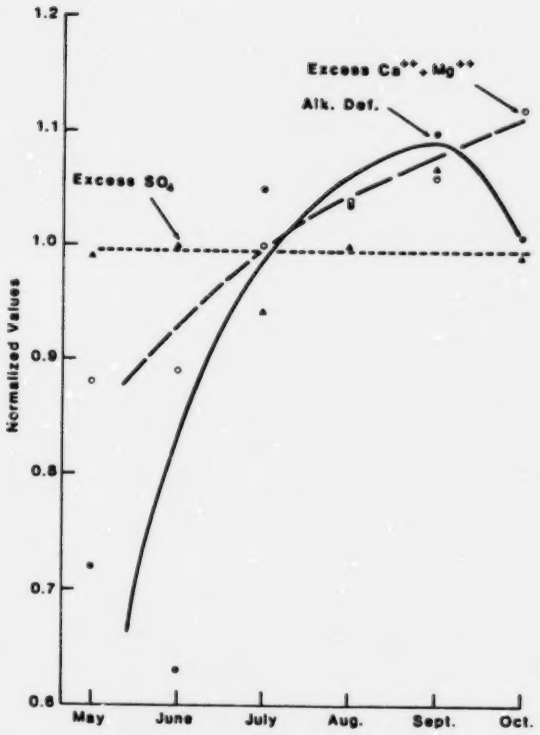


Fig. 17. Normalized monthly means combined for 9 study lakes (Bolton excluded) are plotted for Ca^{2+}, alkalinity deficit (defined in text), and SO_4^{2-}.

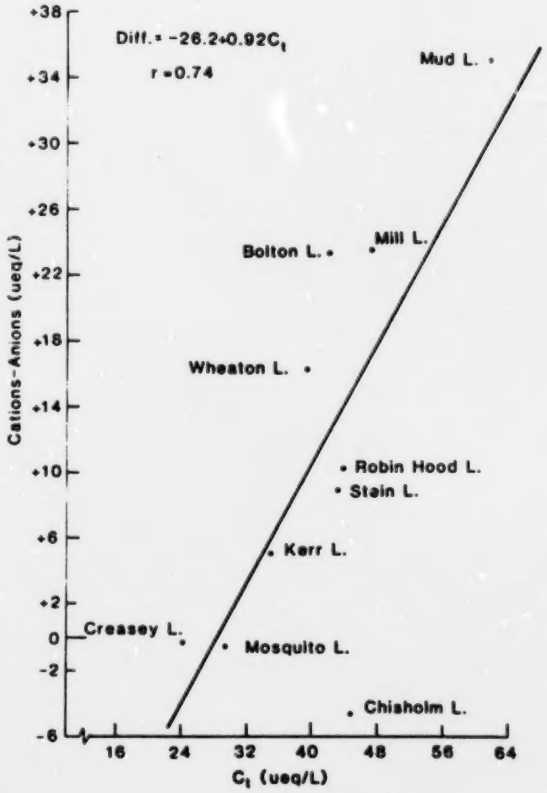


Fig. 16. The differences between sums of cations and anions are regressed on organic anion concentrations (C_t), using Oliver's (1982) relationship.

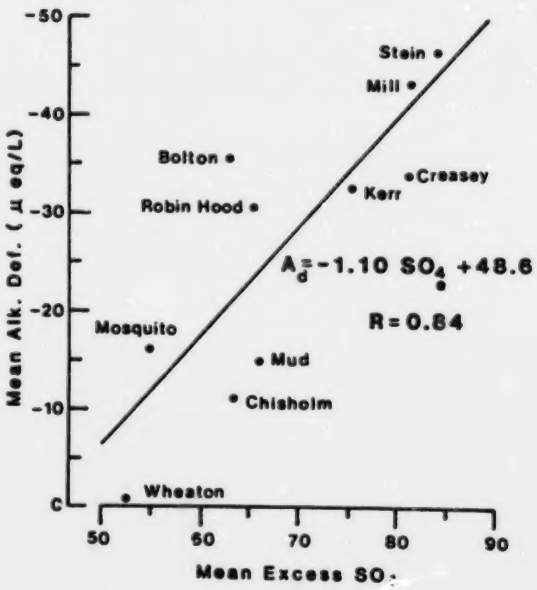


Fig. 18. Mean 1983 alkalinity deficits are regressed on mean 1983 SO_4^{2-} concentrations for the 10 study lakes.

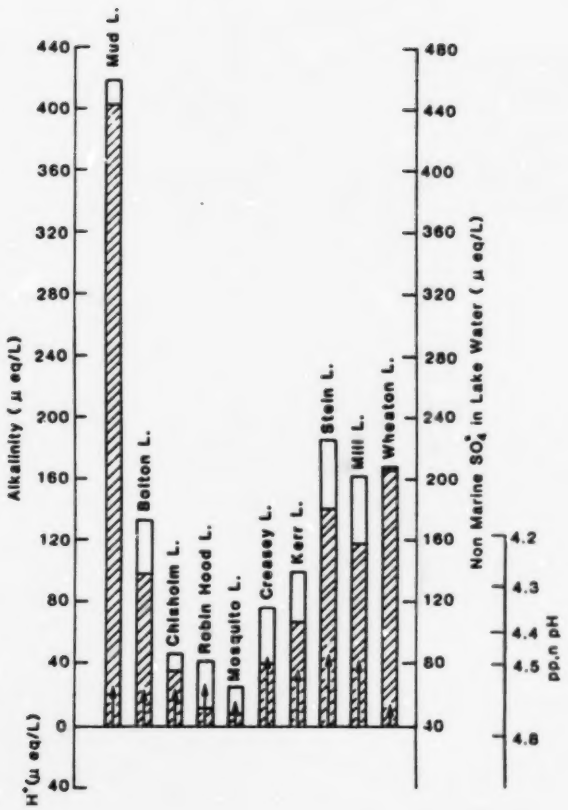


Fig. 19. Diagram showing interrelationships among lake acidification (as measured by loss of alkalinity), excess SO_4^{2-} in lake water, and pp'n. pH (4.5-4.6 for N.B.). Hatched bars indicate present mean alkalinity (HCO_3^-) concentrations in the various lakes. The open bars represent HCO_3^- alkalinity estimated to be present originally (i.e. no acidification). The difference in bar height represents the alkalinity deficit. The arrows indicate the excess sulphate present above "background" of 40 μeq/L. Precipitation pH has been correlated with non-marine sulphate (Henriksen 1982). Pp'n. pH in N.B. is approximately 4.6.

Appendix 1: Surface pH levels for the various study lakes, 1983.

	May	June	July	Aug.	Sept.	Oct.
Mud	6.15	6.40	7.70	7.50	7.35	7.45
Bolton	-	5.85	7.00	7.00	6.95	7.05
Creasey	5.80	5.90	6.75	6.55	6.45	6.60
Kerr	6.35	6.55	6.90	6.85	6.70	6.80
Stein	6.60	6.20	7.10	7.15	6.95	7.10
Wheaton	6.30	6.40	7.20	7.20	7.20	7.15
Mill	6.50	6.45	7.00	7.10	6.95	7.15
Mosquito	5.50	5.60	5.90	5.80	5.95	6.05
Robin Hood	5.70	5.60	5.80	5.85	6.05	6.15
Chisholm	5.80	5.90	6.10	6.15	6.10	6.45

Appendix 2: Surface water conductivities ($\mu mho/cm^2$) for the study lakes, 1983.

	May	June	July	Aug.	Sept.	Oct.
Mud	45	56	57	61	62	59
Bolton	-	18	23	23	24	24
Chisholm	15	20	22	21	20	22
Robin Hood	16	20	18	20	19	19
Mosquito	15	17	19	19	19	19
Creasey	20	27	29	29	27	27
Kerr	20	28	27	34	27	29
Mill	35	38	38	37	38	41
Stein	31	37	37	38	39	40
Wheaton	49	55	51	48	52	51

Appendix 3: Chloride concentrations ($\mu eq/L$) for the various lakes, 1983.

	May	June	July	Aug.	Sept.	Oct.
Mud	31.0	25.4	28.2	28.2	28.2	31.0
Bolton	-	25.4	25.4	25.4	25.4	25.4
Chisholm	45.1	48.0	45.1	42.3	50.8	53.6
Robin Hood	53.6	42.3	45.1	48.0	45.1	48.0
Mosquito	67.7	56.4	59.2	53.6	59.2	59.2
Creasey	67.7	64.9	67.7	67.7	70.5	70.5
Kerr	67.7	64.9	70.5	67.7	67.7	70.5
Mill	81.8	73.3	79.0	76.2	84.6	93.1
Stein	76.2	70.5	73.3	67.7	67.7	76.2
Wheaton	180.5	177.7	183.4	172.1	183.4	194.6

Appendix 4: Na^+ concentrations (μeq/L) for the various lakes, 1983. Figures in parentheses are calculated to be of sea salt origin. Total concentrations are the sum of the two figures.

	May	June	July	August	Sept.	Oct.
Mud	17.0 (26.5)	26.1 (21.7)	28.1 (24.1)	32.4 (24.1)	28.1 (24.1)	25.7 (26.5)
Bolton	-	21.8 (21.7)	21.8 (21.7)	30.5 (21.7)	21.8 (21.7)	17.5 (21.7)
Chisholm	17.9 (38.6)	15.4 (41.1)	22.3 (38.6)	29.1 (36.2)	26.1 (93.5)	28.1 (45.9)
Robin Hood	19.4 (45.9)	24.7 (36.2)	26.7 (38.6)	19.8 (41.1)	22.3 (38.6)	19.8 (41.1)
Mosquito	16.0 (58.0)	21.3 (48.3)	40.6 (50.7)	23.7 (45.9)	18.9 (50.7)	18.9 (50.7)
Creasey	20.3 (58.0)	22.8 (55.5)	20.3 (58.0)	20.3 (58.0)	22.4 (60.3)	22.4 (60.3)
Kerr	16.0 (58.0)	18.5 (55.5)	18.0 (60.3)	16.0 (58.0)	29.3 (58.0)	18.0 (60.3)
Mill	30.0 (70.0)	33.0 (62.7)	36.8 (67.6)	39.2 (65.2)	40.7 (72.4)	37.8 (79.7)
Stein	8.8 (65.2)	22.4 (60.3)	28.6 (62.7)	24.7 (58.0	29.0 (58.0)	17.5 (65.2)
Wheaton	32.6 (154.5)	35.0 (152.1)	38.8 (157.0)	35.4 (147.3)	38.8 (157.0)	29.2 (166.6)

Appendix 5: SO_4^{2-} concentrations (μeq/L) for the various lakes, 1983. Figures in parentheses are calculated to be of sea salt origin. Total concentrations are sums of the two figures.

	May	June	July	August	Sept.	Oct.
Mud	69.8 (3.1)	64.1 (2.5)	63.9 (2.8)	63.8 (2.8)	70.1 (2.8)	63.5 (3.1)
Bolton	-	64.1 (2.5)	55.8 (2.5)	60.0 (2.5)	70.4 (2.5)	64.1 (2.5)
Chisholm	58.0 (4.5)	57.7 (4.8)	53.8 (4.5)	74.9 (4.2)	67.8 (5.1)	67.5 (5.4)
Robin Hood	67.5 (5.4)	68.7 (4.2)	62.1 (4.5)	63.5 (4.8)	78.8 (4.5)	61.8 (4.8)
Mosquito	55.7 (6.8)	54.8 (5.6)	100.3[a] (5.9)	46.7 (5.4)	60.7 (5.9)	56.6 (5.9)
Creasey	78.6 (6.8)	78.9 (6.5)	76.5 (6.8)	81.6 (6.8)	88.8 (7.0)	84.6 (7.0)
Kerr	76.5 (6.8)	76.8 (6.5)	70.0 (7.0)	76.5 (6.8)	76.5 (6.8)	76.3 (7.0)
Mill	79.2 (8.2)	80.1 (7.3)	76.5 (7.9)	86.1 (7.6)	85.2 (8.5)	136.4[a] (9.3)
Stein	86.1 (7.6)	86.7 (7.0)	113.5[a] (7.3)	81.6 (6.8)	86.9 (6.8)	79.8 (7.6)
Wheaton	48.6 (18.0)	55.1 (17.8)	50.4 (18.3)	59.4 (17.2)	54.6 (18.3)	47.1 (19.5)

[a]Anomalous data, not used in calculations.

Appendix 6: Monthly Ca^{2+} concentrations (μeq/L) for the various lakes, 1983.

	May	June	July	August	Sept.	Oct.
Mud	325.6 (1.2)	358.3 (1.0)	448.0 (1.1)	482.9 (1.1)	473.0 (1.1)	447.9 (1.2)
Bolton	-	24.0[a] (1.0)	113.8 (1.0)	128.7 (1.0)	133.7 (1.0)	133.7 (1.0)
Chisholm	45.6 (1.8)	48.0 (1.9)	43.1 (1.8)	48.2 (1.7)	52.9 (2.0)	62.8 (2.1)
Robin Hood	45.3 (2.1)	43.2 (1.7)	53.1 (1.8)	53.0 (1.9)	48.1 (1.8)	58.0 (1.9)
Mosquito	34.7 (2.7)	27.7 (2.2)	42.5 (2.4)	37.3 (2.1)	37.5 (2.4)	37.5 (2.4)
Creasey	72.2 (2.7)	69.8 (2.6)	77.1 (2.7)	77.1 (2.7)	77.0 (2.8)	82.0 (2.8)
Kerr	87.1 (2.7)	82.2 (2.6)	87.0 (2.8)	102.1 (2.7)	102.1 (2.7)	107.0 (2.8)
Mill	141.4 (3.3)	136.8 (2.9)	151.5 (3.2)	166.7 (3.0)	161.3 (3.4)	161.0 (3.7)
Stein	124.2 (3.0)	136.9 (2.8)	156.8 (2.9)	176.9 (2.7)	191.9 (2.7)	196.6 (3.0)
Wheaton	167.5 (7.2)	172.5 (7.1)	167.4 (7.3)	177.7 (6.9)	187.6 (7.3)	186.8 (7.8)

[a]Anomalous values, omitted from calculations.

Appendix 7: HCO_3^- concentrations (μeq/L) for the various lakes, 1983.

	May	June	July	August	Sept.	Oct.
Mud	326.8	363.6	415.6	475.5	411.6	427.0
Bolton	-	0[a]	91.9	93.9	99.9	107.9
Chisholm	16.0	49.9	32.0	36.0	38.0	42.0
Robin Hood	14.0	12.0	16.0	0	8.0	18.0
Mosquito	14.0	4.0	16.0	0	10.0	6.0
Creasey	48.0	36.0	36.0	36.0	51.9	42.0
Kerr	65.9	65.9	61.9	61.9	71.9	75.9
Mill	115.9	115.9	121.9	141.9	145.8	69.9[a]
Stein	85.9	113.9	139.9	155.8	173.8	181.8
Wheaton	163.8	165.8	157.8	163.8	177.8	181.8

[a]Anomalous values, omitted from calculations.

Appendix 8: Mg^{2+} concentrations (μeq/L) for the various lakes, 1983. Figures in parentheses are calculated to be of sea salt origin.

	May	June	July	August	Sept.	Oct.
Mud	33.6 (5.9)	44.6 (4.8)	50.5 (5.4)	38.2 (5.4)	48.1 (5.4)	40.2 (5.9)
Bolton	-	32.2 (4.8)	32.2 (4.8)	26.5 (4.8)	36.3 (4.8)	30.6 (4.8)
Chisholm	12.8 (8.6)	11.5 (9.1)	16.1 (8.6)	16.7 (8.0)	15.1 (9.6)	22.7 (10.2)
Robin Hood	6.3 (10.2)	12.6 (8.0)	10.3 (8.6)	9.8 (9.1)	7.9 (8.6)	14.2 (9.1)
Mosquito	3.6 (12.9)	5.8 (10.7)	3.6 (11.2)	4.6 (10.2)	5.3 (11.2)	7.7 (11.2)
Creasey	20.0 (12.9)	16.5 (12.3)	26.6 (12.9)	17.5 (12.9)	19.5 (13.4)	22.0 (13.4)
Kerr	24.1 (12.9)	28.8 (12.3)	26.1 (13.4)	29.9 (12.9)	28.2 (12.9)	31.0 (13.4)
Mill	30.6 (15.5)	35.5 (13.9)	34.4 (15.0)	34.9 (14.5)	41.5 (16.1)	37.4 (17.7)
Stein	36.5 (14.5)	44.2 (13.4)	47.8 (13.9)	56.2 (12.9)	65.2 (12.9)	56.2 (14.5)
Wheaton	18.3 (34.3)	15.6 (33.8)	21.1 (34.8)	21.6 (32.7)	26.9 (34.8)	21.4 (37.0)

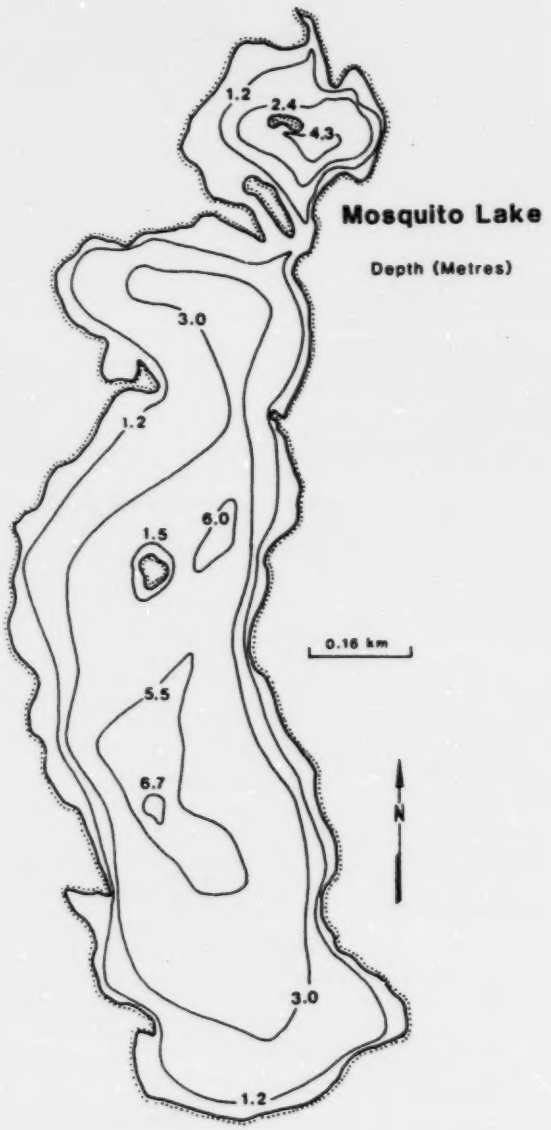
Appendix 9: K^+ concentrations (μeq/L) for the various lakes, 1983. A negative value indicates that the sea-salt correction was larger than the total analyzed.

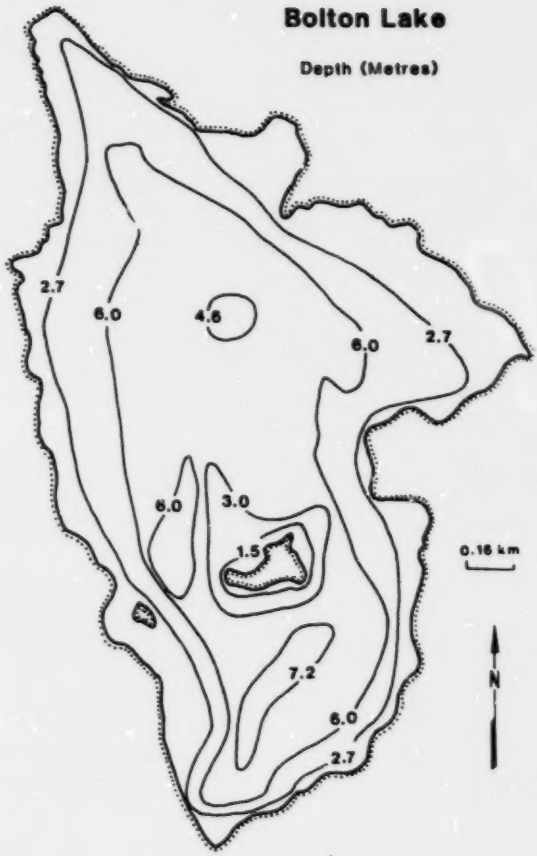
	May	June	July	August	Sept.	Oct.
Mud	17.0 (0.9)	12.0 (0.8)	19.7 (0.8)	19.7 (0.8)	12.0 (0.8)	17.0 (0.9)
Bolton	-	1.8 (0.8)	4.3 (0.8)	4.3 (0.8)	4.3 (0.8)	4.3 (0.8)
Chisholm	6.3 (1.4)	3.7 (1.4)	3.7 (1.4)	3.8 (1.3)	3.6 (1.5)	6.1 (1.6)
Robin Hood	6.1 (1.6)	1.3 (1.3)	3.7 (1.4)	3.7 (1.4)	1.2 (1.4)	1.2 (1.4)
Mosquito	10.8 (2.0)	3.4 (1.7)	13.5 (1.8)	3.5 (1.6)	3.3 (1.8)	3.3 (1.8)
Creasey	0.6 (2.0)	0.7 (1.9)	5.7 (2.0)	5.7 (2.0)	8.1 (2.1)	3.0 (2.1)
Kerr	5.7 (2.0)	3.2 (1.9)	10.7 (2.4)	8.2 (2.0)	5.7 (2.0)	8.1 (2.1)
Mill	2.8 (2.3)	0.5 (2.1)	8.0 (2.2)	3.1 (2.0)	0.6 (2.0)	0.3 (2.3)
Stein	-2.8 (5.4)	-0.2 (5.3)	2.2 (5.5)	2.5 (5.2)	-0.4 (5.5)	1.9 (5.8)
Wheaton	10.4 (2.4)	5.5 (2.2)	10.4 (2.4)	5.4 (2.3)	10.3 (2.5)	10.0 (2.8)

Appendix 10: Organic acid (C_t) concentrations (µmol/L); (-25 to correct for "background").

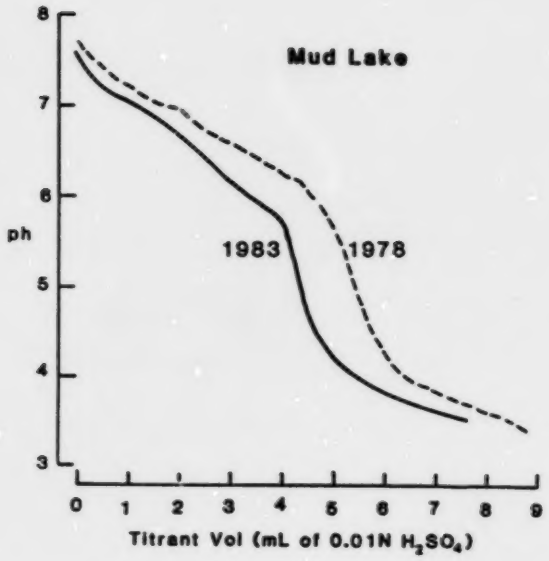
	May	June	July	August	Sept.	Oct.
Mud	30(5)	47(22)	62(37)	75(50)	83(58)	73(48)
Bolton	-	46(21)	41(16)	48(23)	38(13)	37(12)
Chisholm	41(16)	43(18)	49(24)	51(26)	39(14)	48(23)
Robin Hood	38(13)	50(25)	50(25)	41(16)	42(17)	42(17)
Mosquito	19(0)	41(16)	25(0)	23(0)	17(0)	53(28)
Creasey	18(0)	31(6)	35(10)	30(5)	5(0)	32(7)
Kerr	25(0)	35(10)	43(18)	34(9)	34(9)	40(15)
Stein	36(11)	43(18)	49(24)	39(14)	47(22)	45(20)
Wheaton	31(6)	63(35)	175(-)	34(9)	34(9)	35(10)
Mill	42(17)	53(28)	40(15)	53(28)	44(19)	51(28)

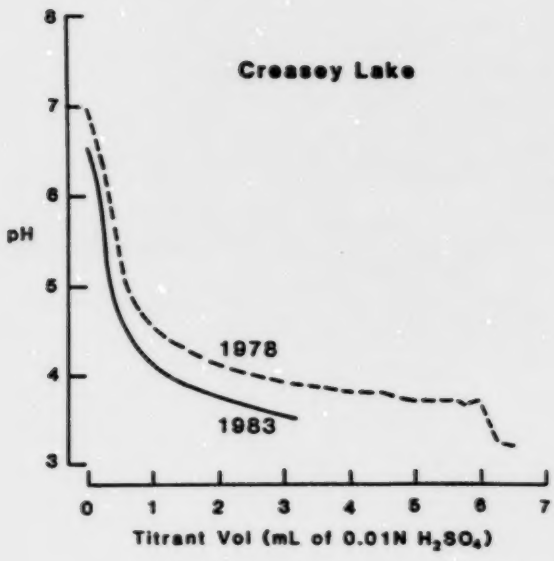
Appendix 11: Morphometrics of two New Brunswick lakes, 1983. Depth contours in meters. Refer to Smith (1952) for similiar information on Kerr and Creasey Lakes.

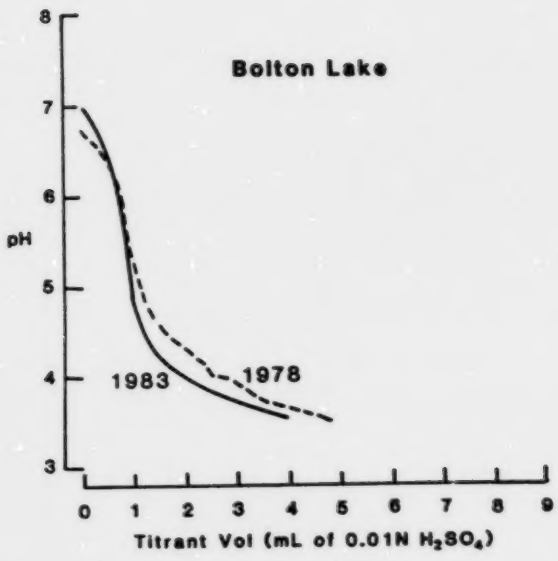


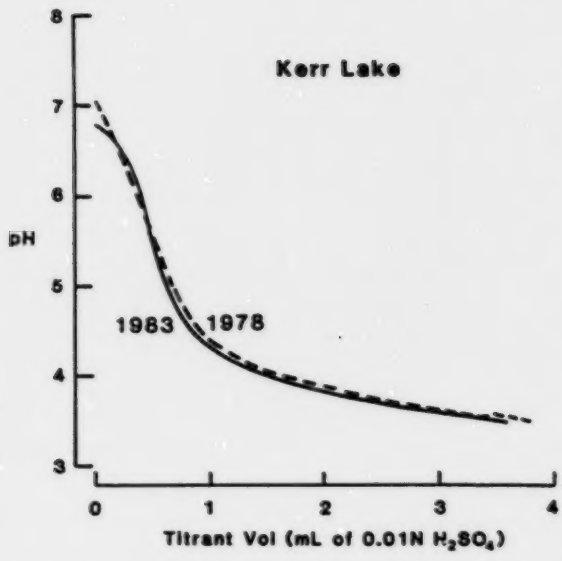


Appendix 12: Alkalinity titration curves for the various lakes, as performed in August, 1978 and 1983.









Appendix 12: (cont'd).